Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 114 (2017) 5948 – 5966

Energy Procedia

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

Demonstration of the Allam Cycle: An update on the development status of a high efficiency supercritical carbon dioxide power process employing full carbon capture

Rodney Allam, Scott Martin*, Brock Forrest, Jeremy Fetvedt, Xijia Lu, David Freed, G. William Brown Jr.[a], Takashi Sasaki, Masao Itoh[b], James Manning[c]

[a]*8 Rivers Capital, 406 Blackwell Street, Crowe Building 4th Floor, Durham, North Carolina 27701, US*
[b]*Toshiba Corporation, 2-4, Suehiro-Cho, Tsurumi-ku, Yokohama 230-0045, Japan*
[c]*Heatric, 46 Holton Road, Poole BH16 6LT, United Kingdom*

Abstract

The Allam cycle is a novel CO_2, oxy-fuel power cycle that utilizes hydrocarbon fuels while inherently capturing approximately 100% of atmospheric emissions, including nearly all CO_2 emissions at a cost of electricity that is highly competitive with the best available energy production systems that do not employ CO_2 capture. The proprietary system achieves these results through a semi-closed-loop, high-pressure, low-pressure-ratio recuperated Brayton cycle that uses supercritical CO_2 as the working fluid, dramatically reducing energy losses compared to steam- and air-based cycles. In conventional cycles, the separation and removal of low concentration combustion derived impurities such as CO_2 results in a large additional capital cost and increased parasitic power. As a result, removal in conventional cycles can increase the cost of electricity by 50% to 70% [1]. The compelling economics of the Allam Cycle are driven by high target efficiencies, 59% net for natural gas and 51% net for coal (LHV basis) while inherently capturing nearly 100% CO_2 at pipeline pressure with low projected capital and O&M costs. Additionally, for a small reduction in performance the cycle can run substantially water free. The system employs only a single turbine, utilizes a small plant footprint, and requires smaller and fewer components than conventional hydrocarbon fueled systems. The Allam Cycle was first presented at GHGT-11 [2]. Since then, significant progress has been made, including detailed system design, component testing and the construction of a 50 MWth demonstration plant commencing in Q1 2016 and now entering commissioning as of Q4 2016. This paper will review the development status of the Allam Cycle; for the demonstration plant, the construction and commissioning status, schedule, key components, layout, and detailed design; turbine design, manufacturing status; development of a novel dynamic control system and control simulator for the demonstration plant; and other key aspects of the cycle. It will provide an

* Corresponding author. Tel.: +1-919-667-1800; fax: +1-919-287-4798.
E-mail address: scott.martin@8rivers.com

Peer-review under responsibility of the organizing committee of GHGT-13.
doi:10.1016/j.egypro.2017.03.1731

update on the progress of the gasified solid fuel Allam Cycle and then address the overall Allam Cycle commercialization program, benefits and applications, and the expected design of the natural gas 300 MWe commercial NET Power plant projected for 2020.

Peer-review under responsibility of the organizing committee of GHGT-13.

Keywords: natural gas, coal, Allam Cycle, carbon, capture, supercritical, update, demonstration, 8 Rivers, Heatric, Toshiba, NET Power, CO_2, sCO_2

1. Introduction

It is imperative that the global community implements a path to achieve significant reductions in current greenhouse gas emissions, principally CO_2. This resolve is set out in the COP-21 protocol [3]. At present, efforts focus on using nuclear and renewable energy sources to meet low-carbon power needs. While these are important clean energy sources, the IPCC 5th Assessment shows that a broader portfolio of low-carbon energy sources is necessary to offer the greatest chance of meeting global climate change targets. In particular, the IPCC 5th Assessment finds that climate models that do not include carbon capture and sequestration in addition to renewable and nuclear energy result in the fewest scenarios in which global temperature rise is maintained below agreed limits. Additionally, the assessment shows that scenarios without carbon capture and sequestration achieve results only with substantially higher costs [4].

The Allam Cycle offers a path to a sustainable energy future by cleanly and economically employing hydrocarbon energy reserves in a process that inherently captures combustion derived CO_2 for sequestration or reuse. The Allam Cycle was originally presented in Kyoto at GHGT-11. It has now reached a mature state of development and will soon be demonstrated using a pilot plant now entering the commissioning stage.

Traditional power cycles, such as natural gas combined cycle (NGCC), supercritical coal cycles, and integrated gasification combined cycles (IGCC), require the addition of expensive, efficiency-reducing equipment in order to reduce and capture emissions of CO_2 and other pollutants. Analyses of these cycles have shown that the additional CO_2 removal systems can increase the cost of electricity by 50% to 70% when capturing typically 90% of the CO_2 generated from hydrocarbon fuel combustion [1]. The Allam Cycle takes a novel approach to reducing emissions by employing oxy-combustion and a high-pressure supercritical CO_2 working fluid in a highly recuperated cycle [5]. The CO_2 that must be vented from the process leaves at pipeline pressure and high quality as a result of the operating conditions of the cycle, thereby mitigating the common necessity of an additional capture, clean-up, and compression system. The cycle is able to utilize a variety of hydrocarbon fuels, including natural gas, unprocessed raw and sour natural gas streams containing H_2S and CO_2, and gasified solid fuels such as coal, oil refining residuals, and biomass. The result is a power cycle with major advantages over conventional systems that do not capture CO_2, attaining 59% LHV efficiency (comparable to best-in-class NGCC power plants not capturing CO_2); significantly higher efficiencies than state-of-the-art coal plants, currently reaching 51% LHV; low capital costs due to the simplicity and high-pressure of the cycle; low ambient cooling requirements, depending on cooling configurations used; and virtually no air emissions, including full CO_2 capture. Additionally, for a small reduction in performance the Allam Cycle can run substantially water free [6, 7, 8].

The Allam Cycle has been under development for 7 years by 8 Rivers Capital. Specific development of the natural gas Allam Cycle has been undertaken by NET Power, a company owned by 8 Rivers, Exelon Generation, and CB&I. NET Power is currently building a 50 MWth natural gas demonstration power plant in La Porte, Texas, soon entering commissioning. The plant will be a fully operational, grid-connected power plant containing all key system components. Further, it will demonstrate the full operability of the cycle, including start-up, shut-down, load following, emergency operations, and partial-load operation in addition to component duration testing.

NET Power is working closely with Toshiba Corporation which is developing and supplying a novel supercritical CO_2 combustion turbine for the cycle [9, 10]. The turbine for the demonstration plant is completed and is in the process of being shipped to site with its electric generator and auxiliary equipment. The advanced high pressure recuperative heat exchanger has been designed and fabricated by Heatric and is already on site.